Acoustic Resonance Classification of Swimbladder-Bearing Fish at Multiple Scales

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LONG-TERM GOALS

To accurately describe the spatial and temporal distributions of fish and to quantify the midfrequency clutter characteristics of fish.

OBJECTIVES

To conduct a new class of quantitative acoustic studies of scattering by swimbladder-bearing fish utilizing new broadband-acoustic technology that is optimized for use in the resonance scattering region of fish. The studies, which include use of long-range horizontal-looking and short-range downward-looking systems, exploit the resonance scattering of the fish to significantly reduce ambiguities in interpretation of echo data.

APPROACH

Building on the success of three previous major experiments, which includes the NRL pilot measurements in 2008, we are now making a fully-integrated set of measurements through two two-ship experiments (Sept. 2010 and Sept 2011) involving a NOAA fisheries vessel and a UNOLS

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research vessel. We are exploiting the broadband capabilities of each of the midfrequency acoustic systems (WHOI-Edgetech and NRL systems), along with their complementary deployment geometries (short-range downward-looking vs. long-range horizontal-looking, respectively) for both resonance classification of swimbladder-bearing fish and characterization of their patchiness at different spatial and temporal scales. Complementing these midfrequency measurements is use of nets to sample the fish and traditional high frequency acoustics for intercomparison with standard techniques.

The end result of the measurements would be first-of-a-kind maps of distributions of swimbladder-bearing fish in two planes (vertical and horizontal) as derived from two broadband midfrequency sonars at multiple scales. *What makes these results unique and powerful is that, not only are the data to be collected at high spatial resolution in these two orthogonal planes, but the data are also broadband and contain resonance information eliminating significant ambiguities in interpretation.* In addition, key parameters (relevant to Navy signal processors) of the echo statistics of the long-range sonar due to the patchiness would be determined, allowing the development of physics-based bioclutter models and clutter-reduction methods.

WORK COMPLETED

Completing work from previous cruises:
Finalizing data analysis of September 2008 cruise (mixed assemblage analysis) and submitting new paper. As given in detail in the FY09 report, the key feature of the data was the consistent presence of two resonance peaks in the broadband acoustic data, indicative of two size classes of fish in the patches. This apparent mixed assemblage, all in the upper water column, was confirmed through analysis of the net samples. Through resonance classification, numerical densities of the different size classes were inferred and compared with the nets. Inferences were made of fish behavior, as there were both predator (larger fish) and prey (smaller fish) present in the same aggregations. The analysis, involving relating resonances to sizes (aided by net samples) and inferring fish behavior, was finalized and submitted to a refereed journal **(Stanton et al., submitted).**

Publishing papers from previous years' research. **a)** The major manuscript that described the newly developed broadband methods and application of the new WHOI-Edgetech system at sea was published. The manuscript described the entire approach, including concept of the resonance classification system, choice of hardware, development of software, calibration procedures, field use, and interpreting data in terms of meaningful biological parameters (fish type, size, and numerical density) **(Stanton et al., 2010)**. This was such an important milestone in the research, that a press release was published: http://www.whoi.edu/page.do?pid=7545&tid=282&cid=70786&ct=162. News and other media published stories based on this press release. **b)** Data collected in this project were used by Stanton and Chu in another ONR grant (Undersea Signal Processing) to study the echo statistics associated with patches of fish in the resonance scattering region (2-4 kHz). A paper describing this analysis was published this year **(Stanton and Chu, 2010).**

Preparing for 2010 cruise:
Calibration of NRL source was conducted in 2008. The existing vertical receive line array of NRL was converted into a towable horizontal array and tested at sea out of WHOI. Signal generation and data processing software in the NRL system was modified and tested for better near real-time capability. The WHOI system was tested off and on at the test well in the WHOI pier throughout the

spring and summer as a means of checking that the system was ready for the 2010 cruise and to refine methods.

Conducting 2010 cruise:
The 2010 ocean experiment, which involved two ships, was conducted during the period September 8-18, 2010. We completed our objective of measuring the spatial distribution of various fish species using several advanced methods that involve different scales, and with the new emphasis on the NRL broadband long-range sonar. A series of coordinated measurements were conducted, mostly over Georges Bank. A small study was also conducted over Franklin Swell on the way back to port. There were coordinated measurements between the following combinations of intercomparison measurements-- WHOI-NMFS, WHOI-NRL, NRL-NMFS, and WHOI-NRL-NMFS. In each intercomparison, the spatial distribution of fish was studied through the different sensing tools each institution brought. The spatial distribution was characterized over a range of scales, from fine scale with the downward-looking echo sounders through large scale with the long-range sonar. Through a combination of resonance classification of the fish, short- and long-range sonar, and net samples, the spatial variability of different size classes and species of fish was studied. These studies are unique and are fertile material for studying the fish behavior.

Ancillary activities. 1) Wendy Petersen of NUWC participated in the NRL component of the experiment in order to extract fish echoes from the NRL system for a Navy tracker data base. 2) LCDR Ben Jones (NPS, funded by the Navy and Mike Vacarro's HiFAST program) participated in the NRL component of the experiment in order to use fish echoes from the NRL system to ground predictions in the HiFAST project.

Spatial characteristics of fish. The NRL long-range sonar data showed distinctly different characteristics in the patchiness of the fish, depending upon whether they were at Georges Bank (Fig. 1a) or Franklin Swell (Fig.1b). The patches of fish were generally elongated over Georges Bank, but occurring in sparser, more compact aggregations in Franklin Swell. Averaging over pings helped to eliminate left-right ambiguity, as illustrated in Fig. 2. Supporting measurements of the spatial distribution were made with the WHOI-Edgetech system and high frequency acoustics system.

Resonance classification of fish. Both the WHOI and NRL broadband systems observed one or more resonances in any given set of data over Georges Bank. Peaks in the echo spectrum were typically observed in the range 2.5 – 3.0 kHz as well as sometimes at higher frequencies near 6 kHz. These peaks can be related to size of fish present. Net samples confirmed that there were different size classes of fish present.

Non-Rayleigh nature of echo statistics. The statistical properties of the echoes also varied with region. The echo amplitude probability density functions (PDFs) of the echoes were generally Rayleigh-like when the NRL beam swept across the elongated features of fish patches over Georges Bank and were strongly non-Rayleigh when the beam swept across the sparse compact patches over Franklin Swell (Fig. 3).

Range-dependent waveguide information. XBTs were collected along the gradient of depth to measure the spatial variability of the sound speed profile (Fig. 4). Here, the data illustrate the well-mixed layer near the surface when over the bank and the stratification when away from the bank. These data will

be used to model the range-dependent acoustic waveguide which, in turn, will be used to interpret the long-range echo data.

RESULTS

1. Characterization of mixed assemblages of fish (short-range, downward-looking broadband system) (2008 cruise data). Through the use of broadband sound, we have been able to quantify the major size classes present in each aggregation. Whereas traditional narrowband systems cannot determine the size classes, broadband sound can spectrally resolve the sizes. With pulse-compression techniques, we have been able to produce high resolution maps of the different size classes within a patch which is allowing us to study biological processes.

2. Spatial and temporal variability of fish aggregations (long-range, horizontal-looking broadband system) (2010 cruise). Much high quality data were collected that will be used to quantify the spatial and temporal characteristics of fish. The early analysis shows that the spatial characteristics of the fish are specific to geographical region. Also, the echo statistics were region-specific demonstrating the variability of clutter characteristics of the fish with respect to region. These data were collected rapidly with the long-range acoustic signal. Through spectral analysis, the presence of different size classes was observed.

IMPACT/APPLICATIONS

With the exception of the pilot cruise for the NRL team, this substantial set of broadband long-range data is a first of a kind and will reveal important information on the behavior of fish. Through the instant long-range insonification, the patches of fish were rapidly observed for the different regions. Through spectral analysis, the presence of different size classes was observed. This approach sets a new high standard by which acoustic measurements should be made: using broadband sound in two planes (vertical and horizontal). In addition to the scientific benefit, valuable information quantifying the clutter characteristics of the fish was obtained that can be used for sonar performance predictions in ASW applications.

RELATED PROJECTS

1. Stanton has been funded through the Undersea Signal Processing Division of ONR to study the statistics of the fish echoes (sequence of grants N00014-07-1-0232 and N00014-09-0428). The data from this (Biology) program have been used as a basis for studying echo statistics of midfrequency echoes due to the presence as fish (Stanton and Chu, 2010) as well as to inspire development of new advanced theoretical formulations for echo statistics. **2.** Stanton is making plans with Drs. Brian LaCour and Jim Gelb of ARL/UT, and LCDR Ben Jones of NPS to *transition* the new knowledge that originated in this project (WHOI-Edgetech and NRL) to an advanced Navy active sonar simulator. Several Navy systems are targeted for the transition. The next step in the transition is our planned participation in the upcoming ONR HiFAST FNC (Future Naval Capabilities) program with Mike Vaccaro (Code 321) as Program Officer. **3.** Gauss is participating on a PEO C4I & Space (PMW 120; Marcus Speckhahn) panel to help develop a phenomenological approach that can nowcast/forecast spatial distributions of biologics for mid-frequency ASW applications based on oceanographic, biologic, and acoustic data and models. Gauss is also on the ONR 321 (Kevin Williams) Applied Reverberation Modeling Board (ARM-B) whose charter it is to understand the limitations/major

challenges presented by today's and tomorrow's active sonars relative to reverberation and clutter predictive capabilities, and recommend solutions (the way ahead). Its initial focus is on mid-frequency active monostatic sonars. Both of these high-profile positions allow Gauss to identify and act on technology insertion points. Additionally, Gauss has in transition to CNMOC's Oceanographic and Atmospheric Master Library (OAML) the first Navy-standard Fish Scattering Strength (FSS) algorithm. The planned Stanton enhancements to his scattering formulations could serve as a basis of FSS upgrades. Gauss has been developing moment-based clutter-rejection techniques that could be feed into the Echo-Tracker-Classifier (ECT) baseline processor developed/maintained for the Navy's surface ships' MF active sonars by ARL:UT (Karl Fisher). Gauss is also working with NUWC (Wendy Petersen—2010 cruise participant) regarding providing bioclutter data as a potential upgrade to the Characterization and Reduction of Active False Tracks (CRAFT) database.

PUBLICATIONS

2010 Stanton, T.K. and D. Chu, "Non-Rayleigh echoes from resolved individuals and patches of resonant fish at 2-4 kHz," *IEEE J. Ocean. Eng.*, **35**: 152-163. [refereed]

2010 Stanton, T.K., D. Chu, J.M. Jech, and J.D. Irish, "New broadband methods for resonance classification and high-resolution imagery of fish with swimbladders using a modified commercial broadband echosounder," *ICES J. Mar. Sci.*, **67**: 365-378. [refereed]

Stanton, T.K., C. Sellers, and J.M. Jech, "Resonance classification of mixed assemblages of fish with swimbladders using a broadband echosounder at 1-6 kHz. Submitted to *Can. J. Aq. Sci.* [refereed]
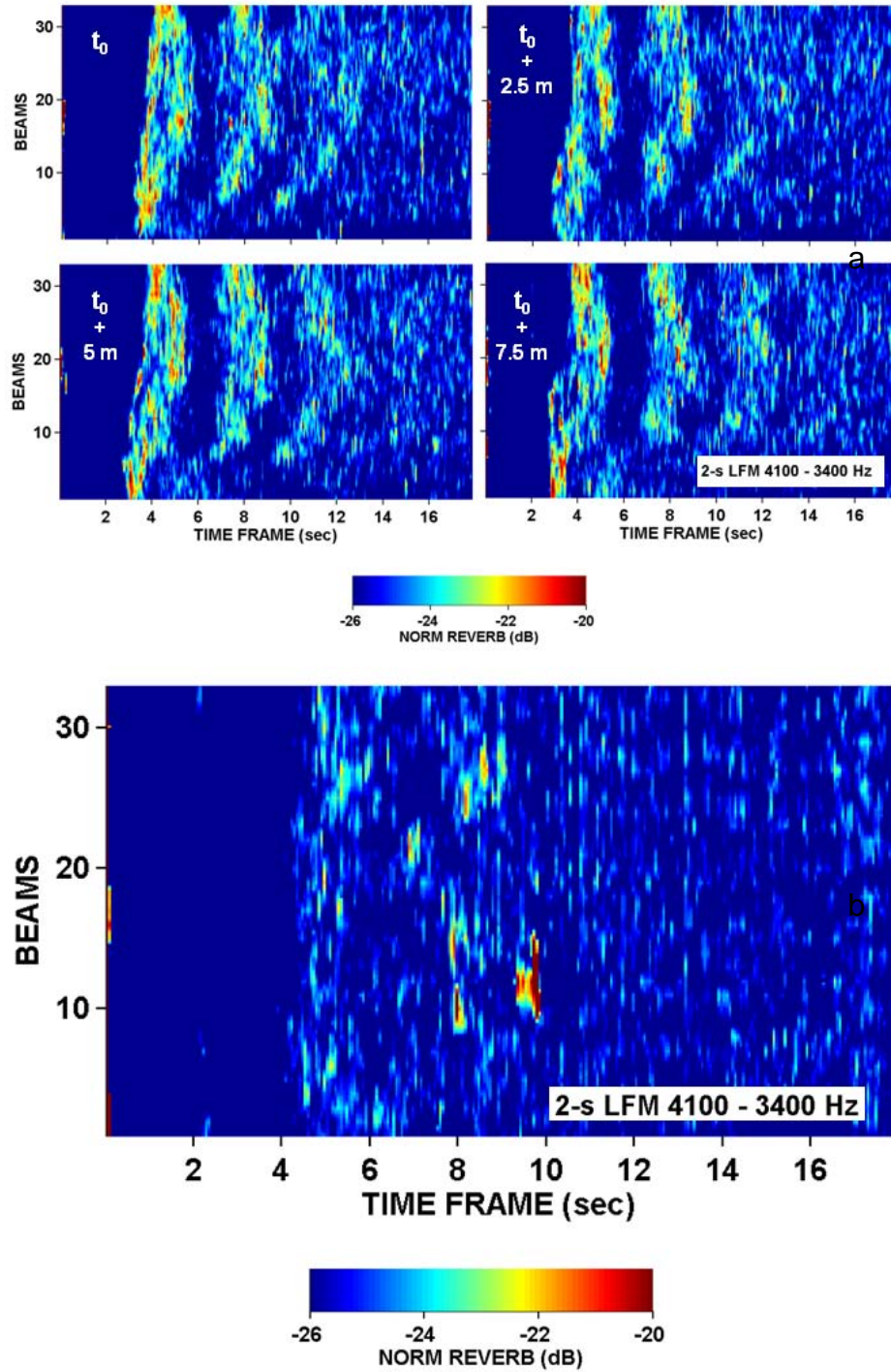
Figure 1. Long-range broadband echoes from patches of fish in two regions: a) Georges Bank and b) Franklin swell. This illustrates the significant change in patch structure between the two regions—shoals and sparse compact patches, respectively. The banded structure in (a) is due to convergence zone effects. All data are matched filtered and energy normalized.
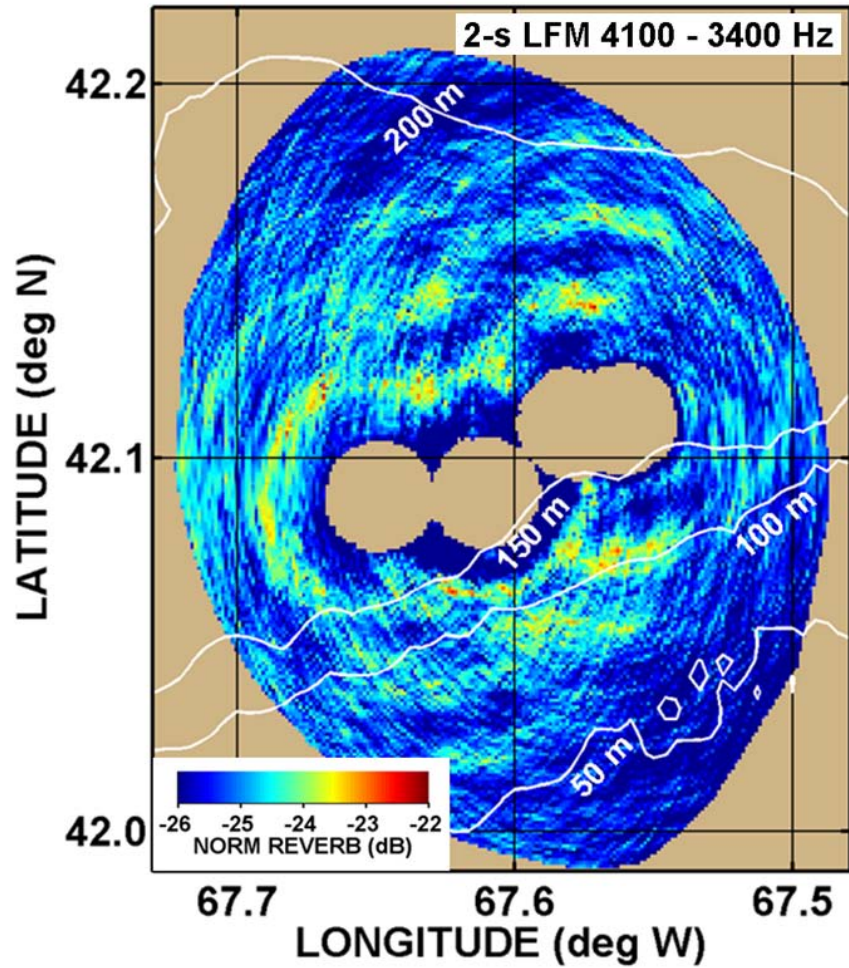
Figure 2. Georeferenced echoes from an average of four pings at distinct location and bearings collected with the long-range sonar on the northern flank of Georges Bank. The averaging serves to reduce or eliminate left-right ambiguity of the receive line array. As in Fig. 1, the banding is due to convergence zone effects. All data are matched filtered and energy normalized.
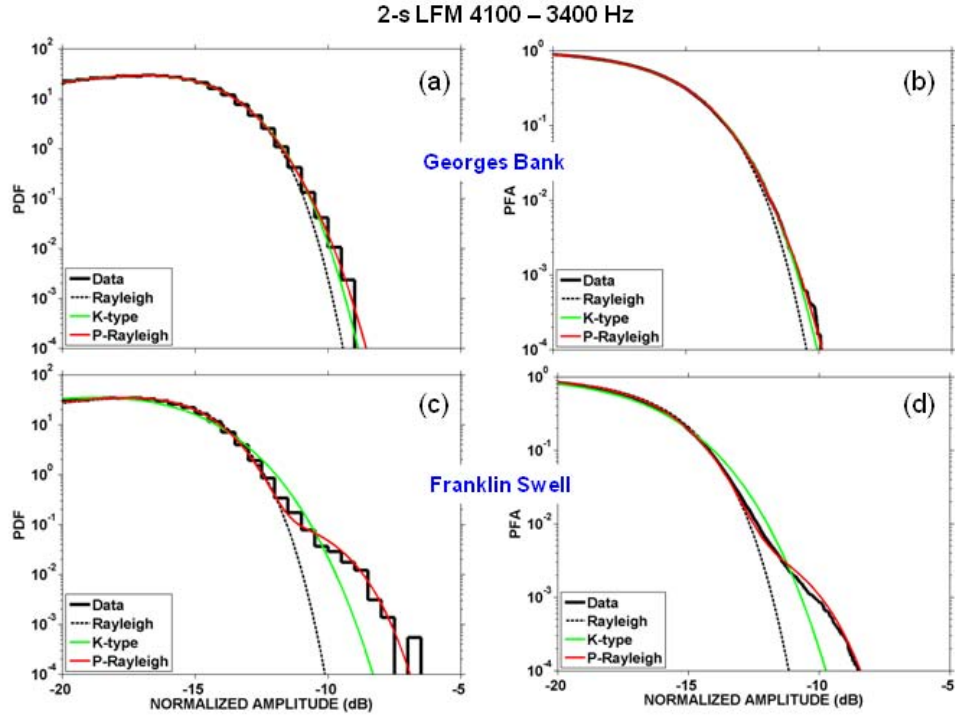
Figure 3. Echo statistics from two regions as collected with the long-range sonar—Georges Bank (upper row) and Franklin Swell (lower row). Probability Density Function (PDF) is given in the left column and Probability of False Alarm (PFA) is given in the right column. The significantly raised tail from the Franklin Swell area is due to the sparse compact nature of the patches of fish.
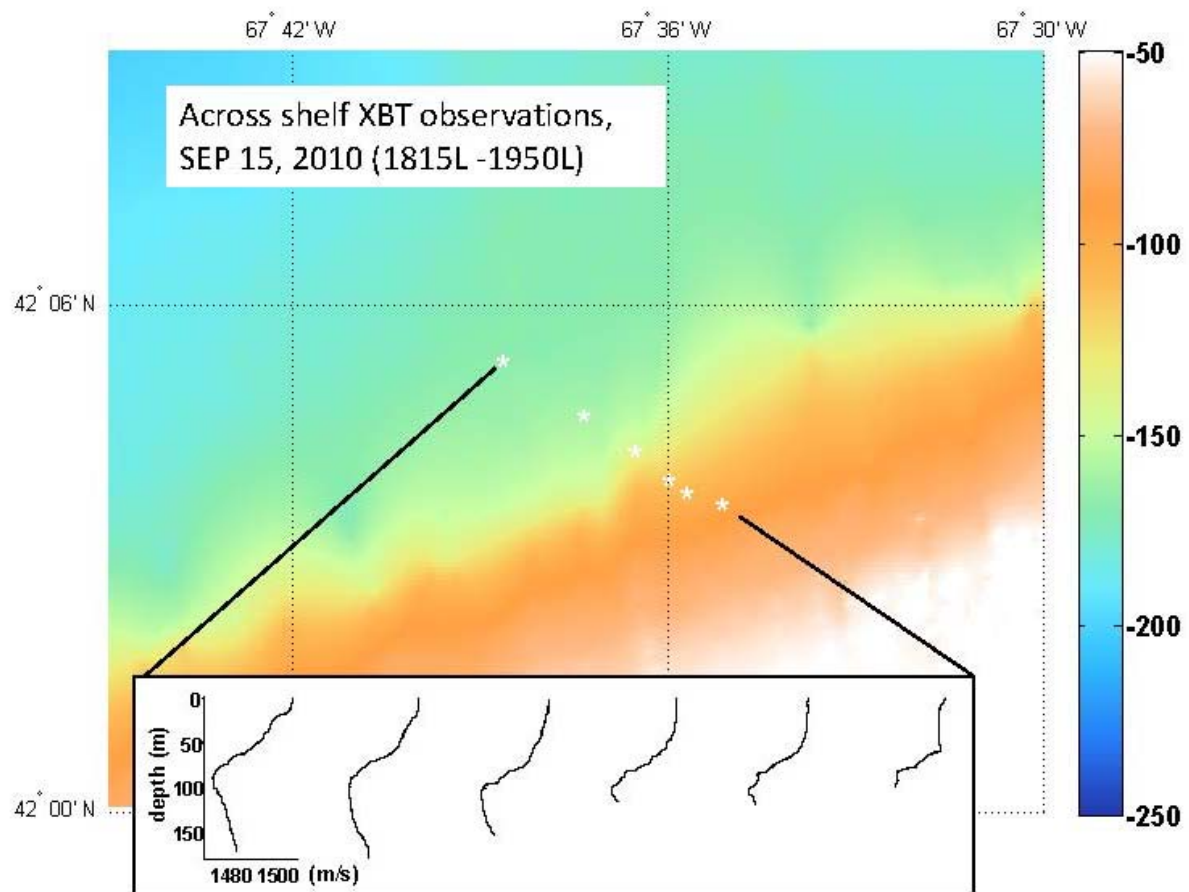
Figure 4. Sound speed profiles collected along the gradient of depth. The variability with location demonstrates the need to account for a range-dependent waveguide in interpreting the echoes from the long-range sonar.